BIOMIMETIC CONTROL ALGORITHM FOR THE BALANCE AND LOCOMOTION OF WALKING SYSTEMS

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Abstract: Implementation of active control has much potential to contribute to the creation and construction of innovative structures. This paper summarizes recent research of the authors that is the study of biomimetic control solutions regarding balance and locomotion of robotic systems. A first goal of the work consists in identifying solutions necessary to balance the individual systems. Research has been focused both on systems with a single foot, but also on biped, tripods, quadrupeds, hexapods and octopods. Static balance is achieved by a proper mechanical design (Bizdoaca and Petrisor, 2009), but also by a corresponding load / tensioning actuators systems that can compensate for inertial elements that can lead to system stability limit. Theoretical studies have been focused on developing an efficient stepping algorithm in environment with strong uncertainties, known as SSTA algorithm. The article present a series of experiments made with servo actuated and smart actuated (based on shape memory alloy, especially) walking biomimetic structures.

1 INTRODUCTION

Biomimetics (or bionics, biognosis, etc.) is an abstract of "good design from nature". Roughly speaking, biomimetics is the concept of taking ideas from nature and implementing them in another technology.This concept is actually very old, for example, the Chinese wanted to make artificial silk 3,000 years ago. Some biomimetic processes have been in use for years. An example is the artificial synthesis of certain vitamins and antibiotics. More recently, the biomimetic concepts, ideas and applications are increasingly reported.

For example, the latest new biomimetic study reported in the journal Nature, according to the current picks of biomimetic issues, is actually from studying how ants avoid traffic jams, which has numerous implications for many scientists to rely on the behavior of ants or other natural systems to give them clues as to how to design computer systems that avoid overcrowded networks. Another biomimetic example, as commented by Philip Ball in the 26 February 2004 issue of Nature in (Hong, and Bruce, 2004), is on the use of microbes in waste-water that could make a handy household battery.

In a more general setting, according to (Whatis.com), biomimetic refers to human-made processes, substances, devices, or systems that imitate nature. The art and science of designing and building biomimetic apparatus is called biomimetics, and is of special interest to researchers in robotics, artificial intelligence (AI), nanotechnology, the medical industry, and the military. Other possible applications of biomimetics include nanorobot antibodies that seek and destroy disease-causing bacteria, artificial organs, artificial arms, legs, hands, and feet, and various electronic devices. One of the more intriguing ideas is the so-called biochip, a microprocessor that grows from a starter crystal in

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much the same way that a seed grows into a tree, or a fertilized egg grows into an embryo.

Biomimetics is now not at the stage in generating new concepts and ideas because the mother nature has already provided numerous models for us to imitate. The key is the implementation and development which is gathering momentum only recently because the science base can cope with the advanced techniques in various areas such as biology, materials, electronics, computing, communication and control etc. The idea of extrapolating designs from nature and copying them has entered into many areas of applied science, most notably the synthesis of new materials. So, it is no surprise that people tend to regard the biomimetics as an interdisciplinary field in materials science, engineering, and biology.

2 STUDY OF BIOMIMETIC CONTROL SOLUTIONS BASED ON THE BALANCE OF INDIVIDUAL SYSTEMS

Studies of the authors have been focused to identify the necessary solutions to ensure the individual systems balance. The research have been directed both on systems with a single foot, which made a movement by jumping, but also on biped, tripod, quadruped, hexapod and octopod systems.

Static balance is achieved by a proper mechanical design [CMSM'2009], but also by a corresponding load / tensioning of actuators systems that can compensate the inertial elements that can lead the system to the stability limit.

In addition to these studies for extension degrees of freedom in order to provide a more efficient navigation and balance control have been explored and studies smart damping and actuation based not only on servoactuators, but and to shape memory materials and magnetorheological fluids.

The essential condition for static equilibrium related to the position of the system gravity centre of which projection must be inside the contact surface described by the support elements (feet) of the biomimetic system is, for jumping and biped systems extremely difficult, while for ensuring a dynamic balance the use of specialized control architectures is required.

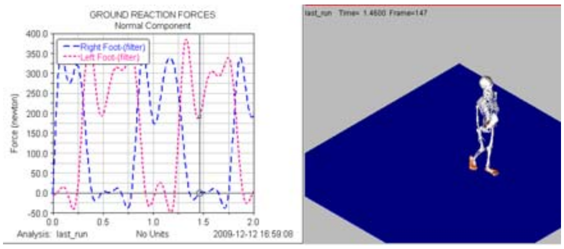

Figure 1: Study of biped locomotion.

Taking into account the human model, it is observed that it has a balanced structure in addition to appropriate state, and a sensorial system that provides the driving of the muscular system to compensate for factors that could lead to system stability limit.

Therefore, to achieve the balance of studied systems, it turned to a series of sensorial elements to ensure the system proximity identification of the stability limit, while an architectural simplification of the system to ensure absolutely necessary degrees of freedom for a dynamic compensation but much more limited than the biological model.

These considerations are related to the complexity of calculations necessary to some systems with more degrees of freedom, respectively considerations of ensuring the bionic system mobility, especially with a lower energy consumption.

Calibration bionic system proved to be a basic element, that essentially influenced subsequent locomotion of the mechatronic system.

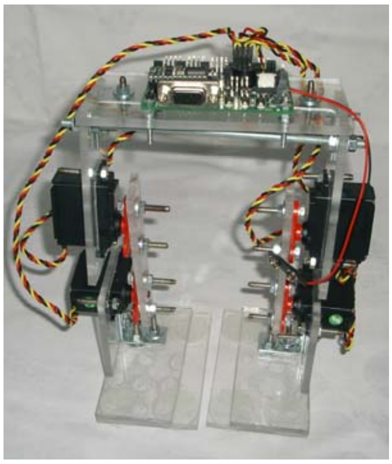

Figure 2: Biped biomimetic structure.

An important component of the study was focused on walking structures issues - quadruped, hexapod and octopod structures.

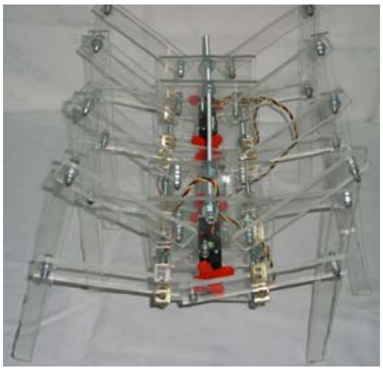

Figure 3: Octopod biomimetic structure.

Figure 4: Quatrupede biomimetic structure.

Consulting literature revealed some aspects of the modalities and criteria for classification of walking robots structures, thus achieving a hierarchy in terms of biological models imitated, of physical morphology, of functions they performed and of locomotion strategy that they adopt.

In order to have a more complete image of the themes (walking robots field), we focused on:

- walking stability issues of such robots
- design advantages of such morphologies
- issues of wide range of areas where they prove their aplicability.

Conclusions resulted in this work led to the need for a dual approach: intelligent design and balancing of the mechanical system and implementing of a system/algorithm that allows the achievement of the instability system compensation or its approach to the stability limit, by the dynamic analysis of the specific conditions.

The developed algorithms should be simple, robust, adaptive, sub-optimal for reasons related to the response time.

3 STUDY OF BIOMIMETIC CONTROL SOLUTIONS BASED ON THE LOCOMOTION OF INDIVIDUAL SYSTEMS

Individual systems locomotion behave correctly identification of the control algorithm, but also, the identification of some kinematic and dynamic models, viable and efficient in implementing of these algorithms through command and control architecture.

Studies of systems moving by jumping with a single leg, with 4 feet, respectively hiperredundante systems, systems that have shape memory springs in their structure, have revealed the effectiveness of this type of solution for continuous monitoring of the damping coefficient necessary at the contact with the ground or for damping and driving of the mechatronic architecture (Bizdoaca, 2009).

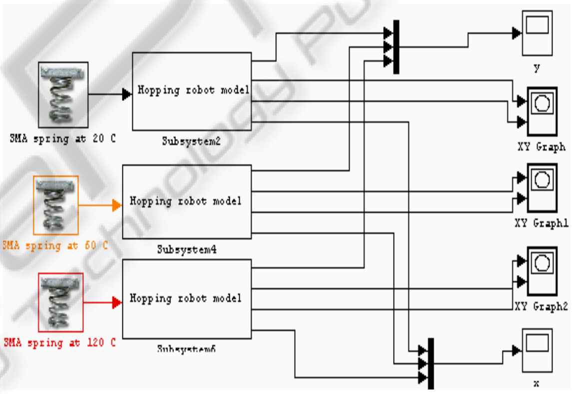

Figure 5: Mathematical model of a one-legged robot that uses as damping element a shape memory spring.

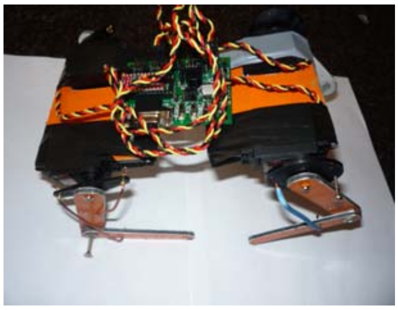

Figure 6: Biomimetic structure type rabbit.

Experimental measurements in conjunction with theoretical and practical work of the research team, have enabled studies to be efficient.

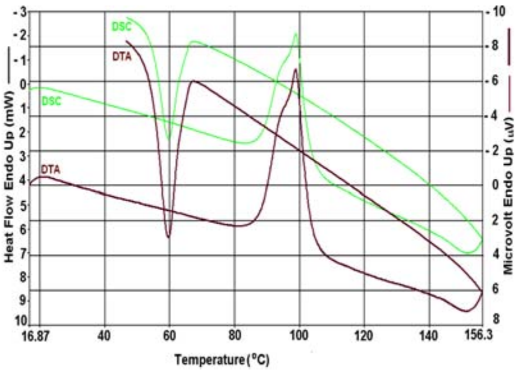

Figure 7: Biomimetic structure type frog. DTA and DSC curves for 18.275mg from SMA spring.

The effect of the energesing smart damping system is extremely efficient, numerical simulations showing this.

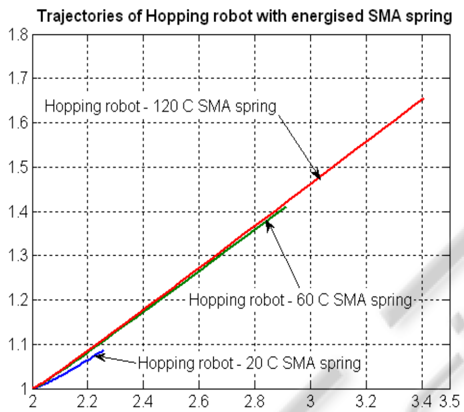

Figure 8: Hopping robot trajectory for different energizing temperatures of the SMA spring.

Particular attention was allocated for the hiperredundante systems both regarding creeping locomotion and handling structures as trunk type.

Kinematic study of walking systems was performed both on the robot body movement in space, given the motion laws of a rigid body in three-dimensional space and on the robot foot considering that it has a structure consisting of three links and three degrees of freedom in relation to the body, achieved by three rotational joints.

The rotation axes for the two joints which form the hip are set to intersect orthogonally.

In the case of existing a defect of the bionic architecture, locomotion was a complement of the activity of the project.

In robotic structures, the faults may be caused by external environmental conditions (operating environment) or by internal conditions (structure, sensors, actuators or control).

Faults monitoring system, according to its complexity, may adopt the following control strategies (from simple to complex): only detection and location of faults and possible suggesting of isolation actions and/or avoiding of fault components; further robot movement until bringing it into a safety state in a neighborhood of the end point for major faults; the robot stop in a safety state with maintaining of stability in the case of catastrophic faults.

General techniques for detection and identification of existing faults and those for recovery after failure, can be applied to walking robots systems, thus determining the operation space under fault. For this purpose were determined the operation areas of the walking robots feet as an annulus sector. Overcoming these allowed operation areas for each leg lead to interference problems.

To avoid this, were a prori eliminated all the areas that can be overcome, so that each leg has its own separate region.

Thus, it was defined for each leg one operation area (called operation cell) having a rectangular shape. Then it was analized, from kinematic point of view, the case of existing a fault due to a blocked joint of a robot leg. This analysis of the fault can be extended to other robot legs because of the robot symmetry.

Based on kinematic restrictions mentioned above, were presented and justified fault-tolerant locomotion algorithms for each considered case of fault both for the straight line robot moving and for a crab stepping type: robot locomotion tolerant at first joint blocking, robot locomotion tolerant at second joint blocking, robot locomotion tolerant at third joint blocking.

4 IMPLEMENTATION OF THE WALKING ROBOT CONTROL ALGORITHM IN SSTA STRATEGY

It is considered the walking robot structure as depicted in Fig.9, having three normal legs L^i, L^j, L^p and a head equivalent to another leg, L^0, containing the robot centre of gravity, G, placed in its foot. The robot body RB is characterized by two position vectors O^0, O^1 and the leg joining points denoted R^i, R^j, R^p. The joining point of the head, L^0, is the central point O^0, R^0= O0, so the robot body RB is univocally characterized by the set,

$$RB = \{O^0, O^1, \lambda^i, \lambda^j, \lambda^p, \lambda^0\}$$

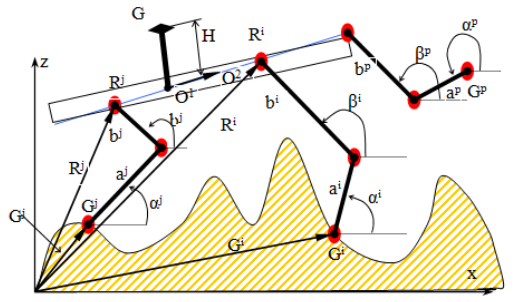

Figure 9: The geometrical structure of the robot.

A robot leg, let us consider of index i, has a body joining point R^i expressed by a complex number and the foot point denoted by the complex number G^i. It contains two joint segments defined by the lengths a^i, b^i with the angles α^i, β^i. Here there are considered three legs: i, j, p.

Due to the complexity of the evolution in an environment with strong uncertaines, an efficient walking algorithm which ensure stability and locomotion of the robotic structure, must be developped.

Stable States Transition Approach (SSTA) control strategy applied for a hexapod structure is proposed. By SSTA strategy is assured the walking robots evolution in uncertain environments subordinated to two goals:

- achievement of the desired trajectory expressed by the functions $O_z^0 = f(x)$ and $\theta = \theta(x)$, where x is the ground abscissa and $O_x^0 = x$; it is considered the evolution from left to right;

- assuarance of the system stability that is, in any moment of the evolution the centre of gravity has to be in the stability area.

Considering the walking robot as a variable causality dynamic system it is possible to realize this desideratum in different variants of assurance the steps succession. The steps succession suposes a series of elementary actions that are accomplished only if the stability condition exists.

Continuously, by sensorial means or using the passive leg, the robot has informations about its capacity of evolving on the ground. Every time it is considered that the legs i, j are on the ground and the the system is stable ($\varepsilon_{ij} \in [0,1]$). The passive leg G^p is which realises the walking.

By testing the ground is realized its division in lots representing the fields on x axis which constitue the abscissas of some points that can be touched by the G^p leg. A next support point given by the free G^p leg, is chosen so that to existe a next stable state ε_{ip} or ε_{jp}, taking into account the actual state of legs activity.

A variant of mouvements succesion, composed by 12 steps, was proposed in (Petrisor, 2008).

5 EXPERIMENTAL RESULTS

An experimental platform, called RoPa, has been conceived. The RoPa platform is a complex of MATLAB programs for simulation and control of walking robots evolving in uncertain environments according to SSTA control strategy. A number of eight causality orderings of the robot structure have been implemented on RoPa.

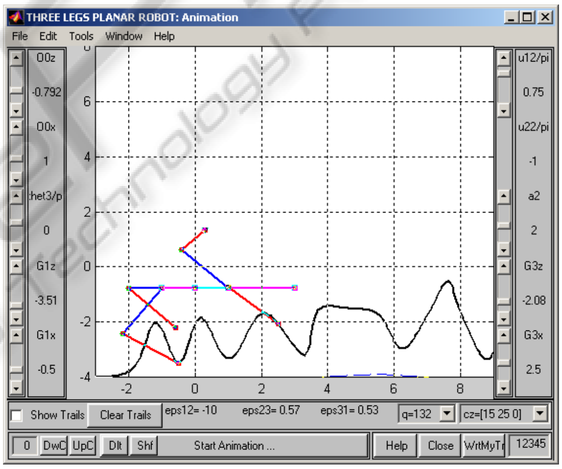

Figure 10: RoPa Graphic User Interface.

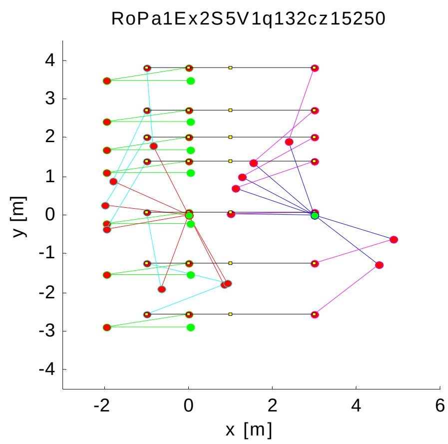

Figure 11: The robot kinematics evolution.

The stability of this evolution is graphical represented by a stability certificate of the evolution (Figure 12).

This certificate attests the stability index of the active pair of legs in any moment.

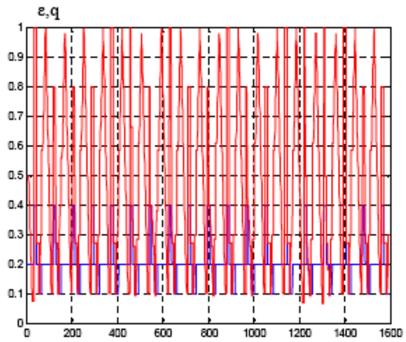

Figure 12: The stability certificate of the evolution.

6 CONCLUSIONS

Experiments on walking structures, made in the mechatronics laboratory, revealed the efficiency of SSTA algorithm, providing a robot system stability especially on hard terrain or with a high degree of uncertainty regarding the nature and topography of the contact surface. Using smart materials in the structure of biomimetic mechatronic architectures lead to an extension of the control capabilities. These latter elements will be explored in subsequent theoretical developments of research activity, practical experimentation, empirical, currently performed being extremely encouraging.

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